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Flushing Study of South Beach Marina, Oregon

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16. ABSTRACT

Recent increases in recreational and small commercial craft activities have resulted in the construction of many new marinas. Local, state, and Federal governments must evaluate applications for marina construction permits. Little information exists on ecological impacts of marinas or of construction events such as dredging and spoil disposal.
This report concerns once aspect of the marina permit evaluation process: water quality impacts related to marina circulation and flushing efficiency. These physical properties vary with the wind, tide range, water density, and physical dimensions of a marina. Water quality is affected by the degree of flushing, and sediment redistribution by currentsl. Detrimental water quality can determine the tate of migrating juvenile fish and benthic organisms. Ecological studies of marinas are few. Most mathematical studies of marina circulation and flushing have been concerned with vertically well-mixed waters in one and two dimensions. Hydraulic model studies of small harbors provide an alternative method of assessing flushing ability.

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Flushing Study of South Beach Marina, Oregon

By Richard J. Callaway[1]

Introduction

Recent increases in recreational and small commercial craft activities have resulted in the construction of many new marinas. Local, state, and Federal governments must evaluate applications for marina construction permits. Little information exists on ecological impacts of marinas or of construction events such as dredging and spoil disposal.

This report concerns one aspect of the marina permit evaluation process: water quality impacts related to marina circulation and flushing efficiency. These physical properties vary with the wind, tide range, water density, and physical dimensions of a marina. Water quality is affected by the degree of flushing, and sediment redistribution by currents. Detrimental water quality can determine, e.g., the fate of migrating juvenile fish and benthic organisms (5,7).

Ecological studies of marinas are few. The most comprehensive have been performed on Marina del Rey, Calif. (3,15,16,17,22). Slotta and Noble (21) analyzed the use of benthic sediments as indicators of marina flushing in several Pacific Northwest marinas. Puget Sound marina water quality studies have also been conducted (10, 11, and an unpublished work by Yearsley).

Marina Model Studies

Most mathematical studies of marina circulation and flushing have been concerned with vertically well-mixed waters in one and two dimensions (1,2,4,6, 18,20).

Hydraulic model studies of small harbors provide an alternative method of assessing flushing ability, although not without deficiencies related to scale distortion. Several hydraulic model studies of Pacific Northwest marinas have been conducted by Nece and Richey and their associates at the University of Washington (9,12,13), and by Slotta and others at Oregon State University (1,20,21).

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Because of the small size of most Pacific Northwest marinas, use of numerical models employing finite difference grids or finite elements is not always practical. In order to utilize the numerical method to its best advantage, very small grids would need to be used; for finite difference analogs employing explicit solutions, this would in turn require small time steps less than the grid size, Δx, divided by the speed of a shallow water wave, $\sqrt{gh}$, for a one-dimensional simulation. For a 328-ft (100-m) grid size in, e.g., a 20-ft (6-m) deep marina [depth + 3.3-ft (1-m) tide amplitude], the time step would need to be less than 13 sec. Smaller grid sizes or greater depth, h, require proportionately smaller time steps and increased computer time.

The Oregon marinas examined at Oregon State University used Froude scale models, as did those constructed at the University of Washington. All of the model studies (except that reported in Ref. 13) were site-specific.

One advantage of an hydraulic model over a numerical one is that small-scale operations relating to mixing can be readily observed and photographically recorded. These phenomena approximate mixing processes which take place in the prototype. No attempt has been made to study vertical exchange processes in either the numerical or hydraulic models. Rather, time and space averages were taken; the water column is assumed to be well-mixed in the vertical. This assumption prevents the reproduction of vertical or horizontal convection currents.

Field Surveys

Dye releases have been used to determine flushing rates in Florida finger canals (2,8,23). Slotta and Tang (20) released dye in Oregon's Chetco estuary boat basin, and compared results with an hydraulic and a finite element model. Discrepancies between field and hydraulic model results were due to the difficulty of obtaining the proper density differences between dye and the receiving water in the hydraulic model. However, depth-averaged concentration versus time curves were similar.

In the field experiments to be described, dye as a tracer was distributed throughout the marina during the middle stage of a flood tide. The last two hours of the flood tide were used to permit the dye to continue mixing. An initial average dye concentration, C_o, was achieved at maximum high tide; ideally this concentration remains constant on the following ebb tide, while dye mass decreases. Assuming no return of dye on the next flood tide, the mass of dye in the marina remains constant while the concentration decreases with an increase of volume during the flood.

These assumptions can be expressed as follows, for dye mass, M, at concentration, C, with increasing volumes represented as $+$, decreasing volumes as $-$, constant volumes as o, for flow, Q, and volume, V:

$$Q^+, V^+ \overset{\text{Flood}}{\rightarrow} M^o, C^-; \quad Q^-, V^- \overset{\text{Ebb}}{\rightarrow} M^-, C^o \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Then, on a flood tide, mass is constant, but $C^- \rightarrow M^o/V^+$; on an ebb, $M^- \rightarrow M^o - C^o V^-$ in which M^o = the mass at the end of a flood tide. Note that it is assumed that the dye is uniformly mixed throughout the basin at the time of initial high tide.

For the case of no direct fresh-water inflow, the volume of water present in a marina can be evaluated in terms of a mean tide level volume, V_o, and variations about the mean. For a mean low tide volume $V_l = V_o - A_o R/2$, in which A_o = mean marina surface area; and R = the tidal range from mean low to mean high water.

The tidal prism volume is $V_p = V_h - V_l = A_o R$. This is the amount of water on an ebb tide carrying with it a mass, M (for the first ebb), at concentration, C_o. At the end of the ebb the mass is, as in the preceding

$$M_1 = M_o - C_o(A_o R) \quad \ldots\ldots\ldots\

$$C_{t+1} = C_t - \frac{QC}{V'}\Delta t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where the subscripts = time; and Δt = the time step. The t_i are in any given time units, not necessarily tidal cycles, with the restriction that on an ebb cycle, $C_{t+1} = C_t$. The equation can also be solved by direct integration.

South Beach Marina Characteristics.—The entrance to South Beach marina is 1.5 nautical miles (2.8 km) upstream of the end of the north jetty at Newport,

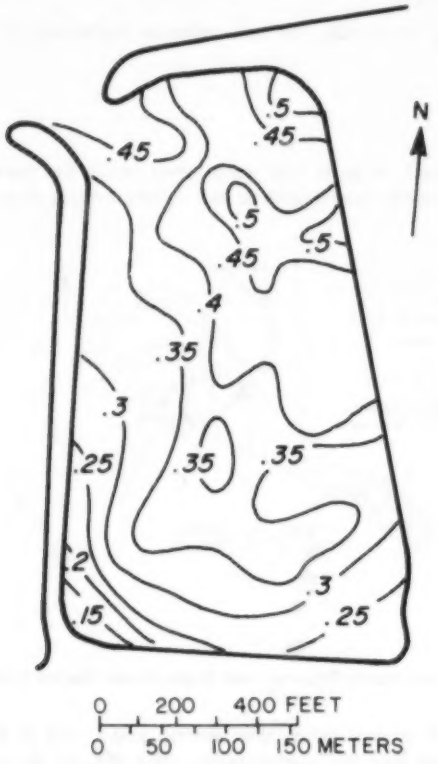

FIG. 2.—Exchange Coefficient Isopleths, South Beach Marina Hydraulic Model (19); Tide Range = 6 ft (1.83 m)

Oreg. (see Fig. 1). Approximate marina dimensions are: length, L = 1,574 ft (480 m); width, W = 623 ft (190 m); depth, d, at mean tide level = 13.4 ft (4.1 m), resulting in a mean tide level (MTL) volume, $V_o = 1.34 \times 10^{-7}$ cu ft (3.74×10^5 m^3); and a mean low tide volume, $V_1 = 1.04 \times 10^7$ cu ft (2.90×10^5 m^3). The mean tide range, R = 6.0 ft (1.83 m), resulting in a mean tidal prism volume, $V_p = R \times L \times W$ of 6.07×10^8 cu ft (1.7×10^5 m^3).

The entrance width is 157 ft (48 m), resulting in a mean cross-sectional entrance area, A, of 2,118 sq ft (197 m^2).

The marina is designed to hold 600 boats. At the time of the field work, no boat slips or piles were in place. Dredge spoil was disposed of on the east bank of the marina. The marina breakwater jetty restricts rapid flowthrough.

South Beach Marina Hydraulic Model Studies.—An hydraulic model study of South Beach marina was made by Richey and Skjelbreia (19). The model used a 1:10 horizontal/vertical distortion ratio; Froude scaling was employed with the following scale ratios: horizontal length = 1:480; vertical length = 1:48; velocity = 1:6.93; time = 1:69.3. The prototype tidal cycle was taken as 12.4 h, which required 10.74 min to reproduce in the model. Sinusoidal tides were used for 0.9-m, 1.8-m, and 2.7-m ranges. Model water density was uniform; boat slips and pilings and wind stress were not modeled.

A 20% solution of rhodamine-WT diluted 1:100 was used as a tracer. Thirty milliliters of dye were completely mixed in the model at high water location.

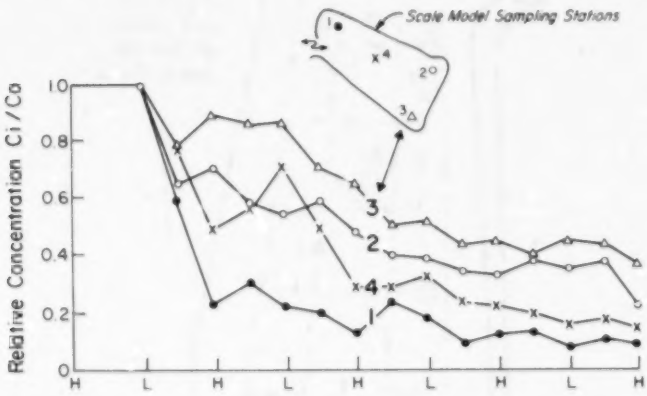

FIG. 3.—Relative Dye Concentration (C_i/C_o) Versus Tidal Cycle, South Beach Marina Hydraulic Model (19)

A Turner Model 110 fluorometer was used to determine relative concentration at the end of four tide cycles.

This procedure was augmented by time-lapse photography of the loss of water-soluble dye with time. The photos were analyzed by a densitometer to obtain relative concentration versus time. Exchange coefficients, defined as $E = 1 - (C_i/C_o)^{1/i}$, were determined from both the dye and densitometer data. Here, C_i = concentration at the ith tidal cycle; and C_o = initial concentration. Exchange coefficients thus calculated are shown for the 5.9-ft (1.8-m) tide in Figs. 2 and 3. Fig. 2 shows E values at the end of four cycles. These are averaged values and range from about 0.15 in the southwest corner to 0.5 in the northeast corner. Low values correspond to relatively low flushing, while higher values indicate greater flushing. This is shown in Fig. 3, where individual C_i/C_o values are 0.35 for station 3, and 0.1 for station 4. This corresponds to $E = 0.23$ and $E = 0.44$ for stations 3 and 1, respectively, which is in the

range of the values given in the previous figure.

The main conclusions of the hydraulic model study were as follows: (1) The basin had good hydraulic characteristics except for poor exchange in the south corners; (2) good exchange is due to strong currents in the main channel passing the marina entrances, which can introduce turbulent eddies on flood tide and prevent recirculation on the ebb; and (3) the currents past the entrance improve the exchange coefficient by about 25% over that where the entrance is situated on a quiet bay.

Field Float Studies.—Weighted poles of 6-ft, 8-ft, 10-ft, and 12-ft (1.83-m, 2.44-m, 3.05-m, and 3.66-m) submerged length were released and followed on

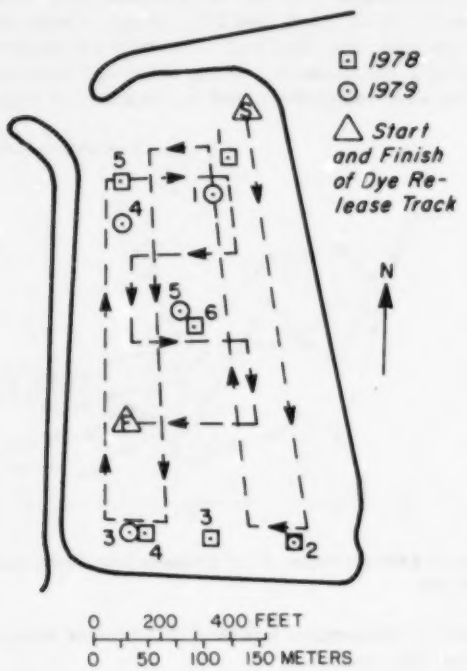

FIG. 4.—South Beach Marina Field Sampling Stations, 1978–1979; Dashed Line Is Approximate Dye Release Track

January 17–18, 1979, in conjunction with a dye release; pole positions were fixed by sextant. Easterly winds ranged from 3 knots–10 knots (1.5 m/s–5 m/s) on the first survey day which was conducted on an ebb tide; 10-knot winds determined the main direction of all pole trajectories during this ebb cycle although a northwest water current component toward the entrance was present. Tide decreased from a maximum [lower high water (LHW)] height of 6.9 ft–3.9 ft (2.1 m–1.2 m), about midtide. Maximum pole velocities observed for the 6-ft and 8-ft poles were 0.8 fps and 0.9 fps (26 cm/s and 27 cm/s), respectively.

Winds were less than 3 knots from the west on the January 18 survey. Tides increased from 6.2 ft–7.5 ft (1.9 m–2.3 m) [higher high water (HHW)]. Although this study was only conducted for a short time, pole trajectories show that surface water near the entrance had a net outward direction, while the deeper layer showed inward motion. Thus, there was some flushing on the incoming tide in the upper layers.

Field Dye Studies.—Rhodamine-WT was released for about 1 h over the entire marina (see Fig. 4) starting about 4 h before slack water on flood tide. Visual observations from the United States Highway 101 bridge at Newport and a light plane did not reveal any obvious high or low surface dye patch concentrations.

Fifty-one lb (23 kg) of 20% dye was diluted with 50 gal (190 L) of seawater to approximate receiving water density from a 55-gal (210-L) drum; it was discharged at about 0.8 gal/min (3 L/min). Two methods of release were used. On the first survey, a 15-ft (4.6-m) hollow aluminum pole with a horizontal discharge tube at the bottom was raised and lowered as the dye was released. The outboard motor vessel made right angle paths throughout the marina. On the second survey, a garden hose was towed at about 45° from the surface to bottom behind the boat throughout the water column; discharge ports in the hose at about 1.5-ft increments allowed for more even vertical distribution of the dye than occurred on the first survey.

At the locations shown in Fig. 4, hourly samples at the surface, middepth, and about 1.5 m from the bottom were drawn from a continuous flow hose-pump arrangement. Samples were taken at hourly intervals for the first 14 h and at mid- and maximum high and low tides thereafter until background levels were approached.

Samples were analyzed on board by a Turner 111 flow-through fluorometer fitted with 546-μ excitation and 590-μ emission filters. Samples for analysis in the laboratory were collected in 125-ml screw-cap containers after local equilibrium was reached as indicated on the field fluorometer. The Turner Designs fluorometer was used in the laboratory. Frequent field calibration was made; laboratory standards were used before and after each run, values reported here are from the laboratory analyses.

Field Study Results

The 1978 study was similar to that of 1979 except for the following differences: (1) Average tide ranges were 7.9 ft and 4.9 ft (2.4 m and 1.5 m), respectively; (2) water column density was different, with a greater rate of change of density with depth for the 1978 study; and (3) the method of introducing the dye was different.

Stratification was slight on each study, the main differences being due to temperature. Salinity and temperature-depth profiles showed a gradual decrease in temperature from 15.6° C to 14.6° C and increase in salinity from 31.6 ‰ to 32.1 ‰ from surface to bottom for 1978.

1978 Survey.—Attempts to distribute dye evenly throughout the water column were not completely satisfactory. Fig. 5 shows surface, mid, and bottom dye concentrations at station 6 (refer to Fig. 4). The surface and middle concentrations were nearly equal to about 1400 on September 15, 1978, but the bottom sample was initially quite low; all samples approached equality after about 0600 on

September 16, 1978. Surface concentrations for all six stations over the duration of the experiment showed similar concentrations except for station 1, which decreased rapidly to about 1800 on the first day. Bottom concentration with time showed station 1 having lower concentrations than all the others until 2200 (September 15) when, again, the concentration lines merged. Stations 2 and 3 showed several spikes which were not apparent in the other values.

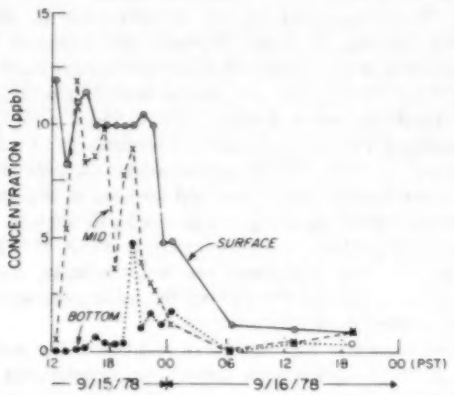

FIG. 5.—Surface, Middle, and Bottom Rhodamine-wt Concentration, in parts per billion, South Beach Marina, September 15–16, 1978

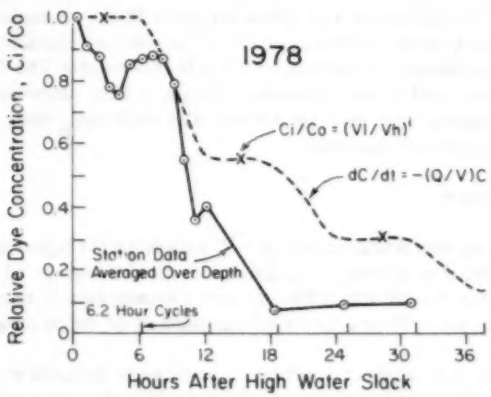

FIG. 6.—Relative Dye Concentration (C_i/C_o) Averaged Over Depth and Model Computations Versus Time, South Beach Marina, September 15–16, 1978

Fig. 6 shows values of C_i/C_o averaged for all stations. The modified tidal prism and numerical model results are also shown. Considering the variability of the dye patches, the first 7 h are in reasonable agreement. A rapid decrease in concentration is shown from hours 7–12 in the models and in the field data.

The latter, however, continue to show decreases to about hour 18.

The 1978 field data can also be compared with the hydraulic model results for the 8.8-ft (2.7-m) range tests. Exchange coefficients in the hydraulic model ranged from 0.44–0.52. Interpolation between the 6-ft (1.83-m) and 9-ft (2.74-m) ranges give $E = 0.44$ for the 8-ft (2.4-m) range found in the field. The exchange coefficient based on the prism method is 0.5 for the 8-ft range. This gives C_i values of 1, 0.55, 0.30, ... on alternate high tides starting with $C_i/C_o = 1$. Field, hydraulic, and mathematical model results all clearly show rapid flushing for this tide range. The hydraulic and mathematical model results are essentially equivalent, but underestimate the dye removed when compared with the field study.

1979 Survey.—For the 1979 survey, the sampling station location was essentially the same as before except that station 3 of the 1978 survey was eliminated (Fig. 4).

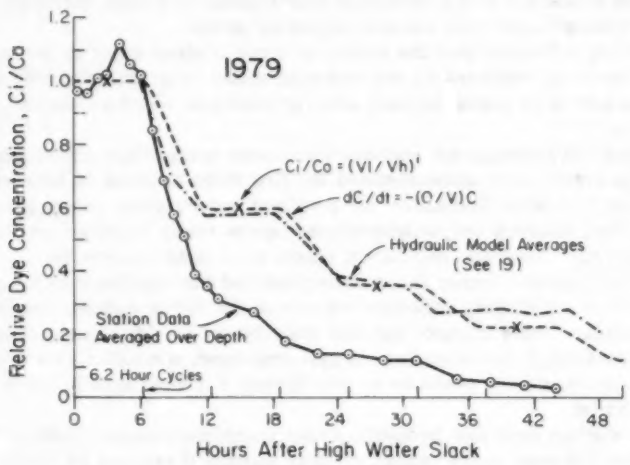

FIG. 7.—Relative Dye Concentration (C_i/C_o) Averaged Over Depth and Model Computations Versus Time, South Beach Marina, January 17–18, 1979

Plots (not shown) of all stations at the surface, middle, and bottom show better initial mixing than in 1978. Station 1, in the northeast corner, initially showed higher concentrations than the other stations but quickly merged with the rest. All data showed an increase in C_i/C_o ratios from about hour 3–7 (ebb cycle), while values at station 4 indicated recirculation south along the west side of the marina.

The hydraulic model results (19) show an average interpolated exchange coefficient of 0.3 for the 6-ft range. The high tide C_i/C_o values at station 1 in the model and field are close; there is an initial rapid decrease in concentration to about $C_i/C_o = 0.2$, followed by a gradual decrease to 0.1 at the fourth tide cycle. Fig. 7 shows the average C_i/C_o results for the hydraulic model as taken from Fig. 3, and the mathematical model values.

For the average results, the discrepancy is rather large giving $V_1/V_h = 0.64$ which results in alternate high tide C_i/C_o values of 1, 0.64, 0.41 .... After hour 12, on the second ebb tide, when the concentration should remain constant, there was only a slight straightening out of the curve; the predicted and observed curves merged after the second flood tide.

Comparisons of Figs. 6 and 7 show that normalized concentration-time curves were quite similar with respect to the sharp decline during the first flood cycle. The 1979 curve shows a steeper exponential decrease toward background concentration.

Summary and Conclusions

South Beach marina has a single entrance and is uncomplicated geometrically; it has free exchange with the main navigation channel where rather large currents develop during ebb and flood tides.

Mathematical and hydraulic models results agreed well when exchange coefficients were averaged over the entire hydraulic model.

Flushing efficiency near the marina entrance is about twice as great as the inner harbor as indicated by the hydraulic model over four high tide cycles. Field results show similar spreads although variations are more extreme among stations.

Neither the hydraulic nor mathematical models successfully reproduced early flushing events; both underestimated the first flood decrease in concentration by about 30%–40%. Thereafter, the predicted and observed curves parallelled each other, although the model-predicted curves remained higher. In terms of pollutant concentrations, both model results were more conservative.

Hydraulic model studies successfully predicted that the South Beach marina would have satisfactory exchange because of the strong currents moving past the entrance. These entrance currents undoubtedly provide significant transfer processes through vortex motion and gyre generation. It is unlikely that a marina of similar dimensions would be as well flushed if it were sited in a less active environment.

The mathematical and hydraulic model comparison raises doubt as to the need for hydraulic model studies of small marinas *if* one can be content with conservative predictions. For marinas of similar dimensions in similar locations, good approximations of flushing efficiency can be made in a matter of minutes using simple box-model assumptions. However, these results cannot be extrapolated to other marinas with multiple entrances, significantly different width-to-length ratios, or environmental settings.

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Appendix II.—Notation

The following symbols were used in this paper:

A = cross-sectional or planform area;
C = concentration;
d = mean tidal depth;
E = exchange coefficient;
g = gravity;
h = maximum depth, shallow water wave;
i = tide cycle;
L = marina length;
M = dye mass;
R = tide range;
T = tidal period;
V = volume;
W = marina width;
α = phase angle;
Δx = grid length; and
ω = frequency ($= 2\pi/T$).

Subscripts

h = high water;
l = low water;
o = mean tide;
p = tidal prism; and
t = time step.

Superscripts

$-$ = denotes decreasing values;
$+$ = denotes increasing values; and
0 = denotes constant values.